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RELATIONSHIP OF WATER BINDING AND pH TO TENDERNESS OF BOVINE MUSCLES[1, 2]

P. E. MCCLAIN[3] AND A. M. MULLINS
Louisiana State University, Baton Rouge

THE most important quality characteristic of meat from the consumer's point of view is tenderness. The exact nature of this elusive characteristic is not well defined, however, some of the factors contributing to meat tenderness are at least partially understood.

Many workers (Wierbicki *et al.*, 1956; Deatherage, 1957; Arnold, Wierbicki and Deatherage, 1956) have concluded that the degree of hydration of the muscle proteins affects meat tenderness. Hamm (1959) postulated that water-binding ability of muscle proteins varies in meat, and factors that affect this property also contribute to tenderness. The relationship of pH to the state of muscle proteins and its effect on water binding and tenderness have been studied extensively (Wismer-Pederson and Briskey, 1961; Bendall, Hallund and Wismer-Pederson, 1963). The ionic atmosphere of muscle tissue and the chemical-physical state of muscle proteins are thought to affect water binding and ultimately tenderness of meat (Swift and Berman 1959). However, changes in tenderness and water binding have not been parallel in many studies, and the exact effect the above factors have on meat tenderness still remains to be elucidated.

Materials and Methods

Muscles from 28 carcasses were divided into tender and less tender groups based on Warner-Bratzler shear values. Selection and treatment of samples for shear value data and chemical analysis have been previously described (McClain *et al.*, 1965a).

Water binding was determined on three muscles using a modification of the procedure of Wierbicki, Kunkle and Deatherage (1957). Equal volumes of muscle and water were blended in a Waring Blendor for 1 min. and pH readings taken using a Beckman-Zeromatic pH meter. Moisture, protein, fat and ash were determined by standard A.O.A.C. methods.

Results

Correlation coefficients for relationships between properties of the three muscles studied are shown in table 1. Negative correlations between water loss and pH were found in all muscles studied, indicating higher water-binding capacity to be associated with higher pH. These results are in agreement with Judge *et al.* (1960) who reported a negative correlation (—.62) between the amount of juice lost during cooking and pH in pork muscles. Since the normal pH of muscle (about 5.5) is close to the isoelectric point, water-holding capacity is at a minimum at this point. Therefore, any rise in pH should increase meat hydration.

Significant negative correlations were found between water loss and moisture content in the *longissimus dorsi* and *triceps brachii* muscles. Moisture content and pH were positively correlated. Correlations between pH and moisture content of muscle, indicated that when pH of muscle was high, moisture content was also high.

In the *l. dorsi* and *semimembranosus* muscles, significant ($P<0.01$) positive correlations between water loss and ash content were found. Hamm (1959) concluded that certain bivalent metallic cations had an important influence on meat hydration. These cations normally occur in muscle and could have an important influence on water-holding capacity even at relatively low concentrations.

A significant positive correlation was found between tissue nitrogen content and ash and between water loss and nitrogen content of *semimembranosus* muscle. Swift and Berman (1959) found that calcium, magnesium and potassium content varied inversely with water retention, and increased with increasing protein content. Conversely, their data revealed iron and zinc content to be directly related to water retention and inversely related to protein content. These workers theorized that

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[3] Present address: U. S. Department of Agriculture, ARS, Human Nutrition Research Division, Beltsville, Maryland.

TABLE 1. SAMPLE CORRELATION COEFFICIENTS BETWEEN SHEAR VALUES, WATER LOSS, pH AND PROXIMATE ANALYSIS DATA IN THREE BOVINE MUSCLES

	Water loss	pH	Nitrogen	Ash	Moisture
L. dorsi					
Shear values (kg)	—.11	0.01	0.21	—.12	0.47*
Water loss (%)	...	—.43*	0.10	0.63**	—.40*
pH	...	...	0.19	—.57**	0.35
Nitrogen (%)	...	...	...	0.31	—.32
Ash (%)	...	...	...	...	—.53**
Semimembranosus					
Shear values (kg)	—.37*	0.22	—.08	—.28	0.16
Water loss (%)	...	—.54**	0.37*	0.40*	—.25
pH	...	...	—.26	—.58**	0.47*
Nitrogen (%)	...	...	...	0.37*	—.56**
Ash (%)	...	...	...	...	—.68**
Triceps brachii					
Shear values (kg)	—.17	0.14	—.17	—.25	—.02
Water loss (%)	...	—.53**	0.13	0.22	—.54**
pH	...	...	—.17	—.54**	0.51**
Nitrogen (%)	...	...	...	0.03	—.38*
Ash (%)	...	...	...	...	—.40*

* Significant at 0.05 level.
** Significant at 0.01 level.

since zinc paralleled pH in its relation to water retention, zinc could participate as a component, or as an activator of an enzyme system which partly determine pH differentials.

The reason for the negative correlation between ash content and pH was not clear. However, electrolyte-pH, enzyme-pH, and electrolyte-enzyme relationships have been reported. Gardner, MacLochlan and Berman (1952) reported the skeletal muscle intracellular pH of normal rats was 6.98, but a corresponding pH of 6.42 was found in the potassium deficient rats. Caldwell (1956) reported that depolarization of the cell membrane with an agent such as a potassium chloride results in an increase in intercellular pH to a value equivalent to the external solution (an increase from pH 5.8 to 7.3). It was suggested that such pH changes could influence enzyme activity. Similar systems could be working in beef muscle and could ultimately affect meat tenderness.

A significant negative correlation between nitrogen and moisture content was found in the *semimembranosus* and *triceps brachii* muscles. This inverse relationship was paradoxical in that protein has been the component of muscle assumed to be responsible for water retention.

Significant correlations were found between percent moisture and shear value in the *l. dorsi* and between water loss and shear value in the *semimembranosus*. None of the other factors were related to shear value in the three muscles. The variation in shear values found between muscles in the less tender group have been previously discussed (McClain *et al.*, 1965b).

Means for the water-binding capacity for the three muscles studied are shown in table 2. Analysis of variance data for the water-

TABLE 2. MEANS FOR SHEAR VALUES, WATER LOSS AND PROXIMATE ANALYSIS DATA IN THREE BOVINE MUSCLES

Tenderness group	N	Muscle	Shear[a] value	Water[b] loss %	pH	Moisture[c] %	Nitrogen[c] %	Fat[c] %	Ash[c] %
Less tender	14	*L. dorsi*	15.00	39.71	5.44	74.11	3.54	2.53	0.91
		Semimembranosus	9.18	41.74	5.46	74.64	3.50	1.96	0.93
		Triceps brachii	9.64	44.96	5.52	75.37	3.31	3.31	0.92
Tender	14	*L. dorsi*	8.37	36.89	5.48	73.65	3.43	3.43	1.00
		Semimembranosus	8.48	40.74	5.46	74.27	3.45	3.45	0.99
		Triceps brachii	8.34	43.89	5.59	75.13	3.29	3.29	0.99

[a] Kg. of shear force on a 2.5 cm. core.
[b] Expressed as a percent of total moisture.
[c] Expressed as a percent of the fresh weight of the sample.

TABLE 3. ANALYSIS OF VARIANCE FOR SHEAR VALUES, WATER LOSS, pH AND PROXIMATE ANALYSIS DATA BETWEEN TENDERNESS GROUPS IN THREE MUSCLES

		Mean squares						
Source of variation	d.f.	Shear value	Water loss	pH	Moisture %	Nitrogen %	Fat %	Ash %
L. dorsi								
Total	27							
Treatment	1	308.29	56.00	0.010	1.51	0.099	4.37	0.06
Error	26	8.30	25.06	0.010	6.27	0.029	2.64	0.02
Semimembranosus								
Total	27							
Treatment	1	3.41	7.09	0.001	0.92	0.017	5.33	0.02
Error	26	2.12	27.79	0.015	3.29	0.035	1.53	0.02
Triceps brachii								
Total	27							
Treatment	1	11.86	8.03	0.039	0.41	0.004	1.43	0.01
Error	26	1.90	19.58	0.035	2.83	0.015	1.19	0.04

* Significant at 0.05 level.
** Significant at 0.01 level.

binding capacity of the muscles revealed no significant differences between tenderness groups (table 3). The *l. dorsi* muscle bound significantly ($P<0.01$) more water than the *semimembranosus* or *triceps brachii* muscles (table 4). In both groups *semimembranosus* and *triceps brachii* muscles were similar in water-binding capacity. There was a significant difference ($P<0.05$) in water loss between the *semimembranosus* and *triceps brachii* muscles in the less tender group, but no difference was evident between these muscles in the tender group. No significant differences were found in pH between muscles or between tenderness groups.

It is evident from these results, that water-binding capacity and pH do not explain the wide variations in shear value observed in the muscles utilized in this study. Other factors which possibly affect meat tenderness have been reported previously (McClain *et al.*, 1965a, b).

Summary

Water binding, pH and proximate analysis data were obtained on the *l. dorsi*, *semimembranosus* and *triceps brachii* muscles from 28 yearling steers, classified as tender or less tender on the basis of shear values for the *l. dorsi* muscles. A negative correlation between water loss and pH was evident for all

TABLE 4. ANALYSIS OF VARIANCE FOR SHEAR VALUES, WATER LOSS, pH AND PROXIMATE ANALYSIS DATA BETWEEN MUSCLES IN TWO TENDERNESS GROUPS

		Mean squares						
Source of variation	d.f.	Shear value	Water loss	pH	Moisture %	Nitrogen %	Fat %	Ash %
Tender group								
Total	41	....	......	....	....	....	....	.....
Muscles	2	0.07	172.06*	0.07	7.71	0.11	0.86	0.006
LD *vs.* SM and TB [a]	1	0.02	274.68**	....	....	0.03	....	.....
SM *vs.* TB	1	0.13	69.64	....	....	0.18	....	.....
Error	39	2.26	33.40	0.02	5.77	0.02	2.70	0.034
Less tender group								
Total	41	....	......	....	....	....	....	.....
Muscles	2	146.73**	27.70**	0.02	5.58	0.20	1.65	0.002
LD *vs.* SM and TB	1	291.98**	31.85**	....	....	0.15	....	.....
SM *vs.* TB	1	1.54	23.75*	....	....	0.25	....	.....
Error	39	5.95	0.48	0.01	2.50	0.01	0.88	0.026

* Significant at 0.05 level.
** Significant at 0.01 level.
[a] LD=*Longissimus dorsi*, SM=*Semimembranosus*, TB=*Triceps brachii.*

three muscles. Negative correlations between water loss and moisture content, and between ash and moisture content were found in the *l. dorsi* and *triceps brachii* muscles. A positive relationship was shown between water loss and ash in these two muscles. A negative correlation was found between nitrogen and moisture content in the *semimembranosus* and *triceps brachii* muscles. Positive relationships were evident between nitrogen and ash and nitrogen and water loss in the *semimembranosus* muscles. No significant differences in the parameters studied were evident between tenderness groups. However, highly significant differences were found between muscles within tenderness groups.

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